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ABSTRACT

The report identifies regions in which deserts and arid zones are increasing; discusses social and climatic causes of deserts; and suggests ways to cope with and reverse problems of famine, malnutrition, and drought. Increasingly, land is being sapped of its ability to sustain agriculture and human habitation north and south of the Sahara, in Iraq, India, the Argentine, Chile, Australia, and the southwestern United States. This is due to overgrazing, soil erosion caused by improper cultivation, and farming without proper soil renewal. Soil cannot hold rainwater in devegetated areas and natural droughts create disasters because water stores become depleted. Underdeveloped countries with large nomadic populations living on arid land have not acquired attitudes of food production for the benefit of the society in general. In these countries, production for individual survival has created problems of unnecessarily large herds and overcultivation. Although technology exists to develop better farming and animal husbandry techniques, people must first accept the resultant change in lifestyle. Solutions include establishment of herding cooperatives, tree planting programs, agricultural modernization, and improvement of grain reserve facilities. (Author/AV)

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Spreading Deserts—The Hand of Man

Erik Eckholm
Lester R. Brown

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Long ago history was made in the deserts. The earliest civilizations and two of the world's major religions were born there. Now the deserts themselves are making news. In the 1970s, world attention is being drawn to arid lands—to some because of the exceptional riches beneath their sands, and to some because ecological deterioration has culminated in human disaster.

Although more than a third of the earth's land is arid or semi-arid, less than half this area is so naturally dry and barren that it cannot support human life. Year after year, however, additional land is converted to waste by humans, who are in many cases forced to compromise their futures by circumstances beyond their control. As a result of the unsound use of land, deserts are creeping outward in Africa, Asia, Australia, and the Americas. Worse, the productive capacity of vast dry regions in both rich and poor countries is falling.

About 630 million people—14 percent of the world's population—live on arid or semi-arid lands. Some 78 million of these people, according to United Nations estimates, live on lands already almost useless because of such factors as erosion, dune formation, vegetation change, and salt encrustation. Those whose livelihoods are not grounded in agriculture may be able to avoid personal disaster amid ecological decline, but perhaps 50 million of these nearly 80 million people face the gradual loss of their livelihoods as their fields and pastures turn into wastelands.[1] They do daily battle with undernutrition, disease, and, when the rains fail, sometimes even starvation. In growing numbers these dispossessed are flocking to overcrowded cities to compete with the rest of the landless for food and jobs.

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6 The worsening plight of tens of millions in the arid zones had long gone unnoticed by most of the outside world. But in 1972, as word spread of a great drought and famine south of the Sahara Desert, countries like Chad and Upper Volta suddenly appeared in front-page newspaper stories. The hollow faces and match-stick limbs of starving humans haunted television screens around the world. While a belated international relief effort eventually eliminated most overt starvation in the afflicted areas, hundreds of thousands of refugees, mostly proud nomads never before so humbled, poured into relief camps and West Africa's cities. And still there were deaths—perhaps a hundred thousand.

A term unfamiliar to most, "the Sahel," soon became common journalistic coin. Actually a geographic description derived from the Arabic word for "shore" and used to denote the narrow band bordering the Sahara, the term "Sahel" has often been used to refer to the six West African countries that faced drought from 1968 through 1973: Mauritania, Senegal, Mali, Upper Volta, Niger, and Chad. In fact, the drought affected not just the Sahelian zone, but also the broader, moister Sudanian zone to its south, which includes most of these six African countries and parts of many others. Even as the West African tragedy was unfolding, droughts and famines struck countries to the east, including Sudan, Somalia, Ethiopia, Kenya, and Tanzania. Although the Sahelian tragedy received more publicity, famine in Ethiopia during the early seventies probably took more lives than the six Sahelian countries together lost.

As awareness of the misery and dislocation of millions of Africans grew, so did the realization that something more than a hiatus in the Saharan fringe's typically low rainfall was occurring. Historians of Africa's desert lands quickly discovered that the ecological calamity triggered by the drought had been stewing for decades. Its roots lay in social and economic patterns incompatible with the region's environmental limitations, and were not touched by the rains that finally returned to most of the Sahel in 1974.

Disasters in the desert are nothing new; drought and crop failures have always plagued arid lands, as Joseph recognized in ancient Egypt

when he advised the Pharaoh to set aside grain reserves. But both the scale of suffering when the rains fail and the scale of destructive human pressures on delicate arid-zone ecosystems are reaching unprecedented proportions in the Sahel and in many other desert regions. As the number of people who rely on the pastures and croplands of the arid zones climbs, once-sustainable social patterns and production techniques begin to undermine the biological systems on which life depends.

Traditional means of coping with drought and of living peacefully with the environment have been rendered inadequate by the modern political and social order, but "development" has not offered desert-dwellers alternative ways to live on the land. Social systems and ecosystems are thus on a collision course; and the question is not whether social and economic patterns in many arid zones will change, but how. Either humans will initiate the economic and political reforms and the technological and demographic changes needed to enhance and protect the land's productivity, or events—sure to be labeled "natural catastrophes" when they occur—will impose social changes as production falls to an ever smaller fraction of its potential.

Desertification: A Global Problem

Long used by some French analysts to describe the desert encroachment and land deterioration they saw in Africa, the term "desertification" has only recently entered the common parlance of the international development community. Once little-known outside scientific circles, the problems encompassed by this concept are, in late 1977, the subject of a United Nations Conference on Desertification to which governments from all over the world are sending representatives.

While "desertification" has become something of a catch-all word, all the problems usually covered by this term involve ecological changes that sap land of its ability to sustain agriculture and human habitation. To many, desertification evokes an image of desert sands relentlessly engulfing green fields and pastures. While desert en-

croachment of such a dramatic sort is a genuine threat in some areas, in most cases one might more accurately think in terms of the desert being *pulled* outward by human actions. Where desert edges are moving outward, moreover, the process seldom involves the steady influx of a tide of sands along a uniform front; rather, climatic fluctuations and land-use patterns interact to extend desert-like conditions irregularly over susceptible land. Spots of extreme degradation are especially apt to grow, for example, around water holes when the nearby pastures are heavily grazed and trampled and around towns when people denude adjacent lands in their search for firewood.[2]

Dangerous as desert encroachment may be, a far weightier threat to human welfare is the degradation of patches of rangeland and cropland throughout the world's arid and semi-arid zones. (See map, pages 22-23.) Such deterioration occurs wherever land is abused regardless of the proximity of true, climatically-created deserts. Where land abuse is severe and prolonged, and especially where extended drought intensifies its effects, grasslands and fields can be reduced to stony, eroded wastelands—or even to heaps of drifting sand. More commonly, the quality of rangeland vegetation declines as the more palatable and productive plants are nudged out by less desirable species. On croplands, yields may gradually fall as soil nutrients are dissipated and the topsoil is eroded by wind and water.

Where and at what pace is desertification unfolding? Documentation is poor even on current soil conditions in many affected areas, let alone on changes in conditions over time. Still, if scientists have not been able to draw precise conclusions, they have used available facts to make valuable estimates of the extent of desertification in various regions. A particularly bold effort has been made by an eminent Egyptian ecologist, Mohammed Kassas. Detailed surveys of climatic data, he observes in a report to the United Nations Environment Program (UNEP), indicate that 36.3 percent of the earth's surface is extremely arid, arid, or semi arid—categories he combines under the general heading of "deserts." Yet a world survey of land conditions, based on soil and vegetation data, indicates that 43 percent of the earth's surface falls within these categories. The difference of 6.7 percent, Kassas suggests, "is accounted for by the estimated extent of man-

"Where land abuse is severe and prolonged, grasslands and fields can be reduced to stony, eroded wastelands."

made deserts."[3] A collective area larger than Brazil with rainfall above the level received in lands classified as semi-arid has been degraded to near-desert through deforestation, overgrazing, burning, and injudicious farming practices. And, it should be stressed, this estimate does not take into account the far greater degradation *within* the zones that are arid or semi-arid in the climatic sense.

Though it is only a rough approximation, Kassas' estimate does suggest the problem's scale. Regional estimates of the spread of deserts and of the degradation of semi-arid lands support the belief that desertification, already a major world problem, is growing in magnitude. It is a malignancy undermining the food-producing capacity of the world's drylands.

The southward encroachment of the Sahara Desert is legend, but it is also fact. If the wilder visions of some nineteenth- and early twentieth-century commentators who believed the desert to be engulfing lands at a terrifying rate have proven overdrawn, that the desert's edge is gradually shifting southward there is little doubt. According to researchers for the U.S. Agency for International Development, an estimated 650,000 square kilometers of land once suitable for agriculture or intensive grazing has been forfeited to the Sahara over the past fifty years along its southern fringe.[4]

The spread of the Sahara has probably been measured most precisely in Sudan. There, as elsewhere, vegetational zones are shifting southward as a result of overgrazing, woodcutting, and accelerated soil erosion. As a number of analysts have described the process, desert creeps into steppe, and while steppe loses ground to the desert it creeps into the neighboring savanna which, in turn, creeps into the forest.[5]

When an aerial survey of Sudan's desert margins was completed in 1975, the photographs were compared with maps that had been prepared in 1958. Examining the line at which scrub vegetation tapers off into barren desert, H. F. Lamprey concluded that "the desert boundary has shifted south by an average of about 90-100 kilometers in the last 17 years." Observations of tree and scrub cover in Sudan

suggest a similar pace of degradation. Dense concentrations of the *Acacia* tree, ubiquitous in many arid zones and useful for firewood, forage, and (in the case of certain species) gum-arabic production, were common around the Sudanian capital of Khartoum as recently as 1955; by 1972, the nearest dense *Acacia* stands stood ninety kilometers south of the city.[6]

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An examination of agricultural trends in the central Sudanian province of Kordofan suggests some of the forces underlying this costly biological march. Livestock numbers in the province have multiplied nearly sixfold since 1957, putting unbearable pressures on grasses and shrubbery. As the human population grows without a simultaneous transformation of agricultural technologies, the traditional cropping cycle—sound and sustainable when followed properly—is breaking down, resulting in both crop-yield reductions and the outright loss of arable lands.

In the past, patches of land covered with *Acacia* scrub were burned clear and then planted with millet, sorghum, maize, sesame, and other crops for from four to ten years. The depleted land was then left idle until the *Acacia* scrub reinvaded it; after eight years or so, the trees could be tapped for gum-arabic, a valuable cash crop, for six to ten years. Finally, as the trees began to die, they were burned, and the cycle began anew. Jon Tinker describes the recent evolution of this system:

> This ecologically balanced cycle of gum gardens, fire, grain crops, and fallow is now breaking down, the 1968-73 drought having in many areas given it the *coup de grace*. Under pressure of a growing population, the cultivation period is extended by several years and the soil becomes too impoverished to recover. Overgrazing in the fallow period prevents the establishment of seedlings. Gum trees are lopped for firewood. More and more widely, *Acacia senegal* no longer returns after the fallow, but is replaced by non-gum-producing scrub. . . . And without the gum to harvest for cash, the farmers must repeatedly replant their subsistence crops until the land becomes useless sand.[7]

Sudan, it is frequently observed, has the theoretical potential to become the breadbasket of the Arab world, given the presence of still unused lands and unexploited rights to Nile River waters. But if the deterioration of Sudan's natural resources is not soon halted, at least some of this potential will dry up.

While land degradation on the southern side of the Sahara has made news in the seventies, land along the northern margins has met with much the same, albeit unpublicized, fate. The population of arid North Africa has multiplied sixfold since 1900, and the destruction of vegetation in Morocco, Algeria, Tunisia, and Libya has accelerated apace—particularly since about 1930, when the region's population began to grow rapidly. Overgrazing, the extension of grain farming onto lands that cannot sustain it, and firewood gathering have all overtaxed the agricultural environment. The result, calculates range specialist H. N. Le Houérou, is the loss of more than a hundred thousand hectares of range and cropland to desert each year.[8]

As the Atlas Mountains to the north erode and as the desert to the south spreads, food production has stagnated in many areas of North Africa. This one-time granary of the Roman Empire is now a major food-importing region. The true extent of the rural deterioration that prevails in much of North Africa is masked by soaring proceeds from petroleum and phosphate exports and by the remitted earnings of the millions who have migrated to Europe for work.

Desertification is by no means limited to the Saharan fringes. It is a major problem in parts of southern Africa, particularly in Botswana. Vast semi-arid grasslands in Kenya, Tanzania, Ethiopia, and elsewhere have been seriously damaged by overgrazing. But its hold is particularly long-lived and advanced in the Middle East and Western Asia. The site of many early human civilizations and the scene throughout history of military invasions from all sides, the arid landscape of this region has suffered many millenia of overgrazing, deforestation, and imprudent cropping. Expanses have been irreversibly transformed by humans into desert, and some areas support fewer people today than they did thousands of years ago. Although many governments in the region have tried to thwart desertification, land damage continues today.

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The rangelands of northern Iraq, forage specialists figure, can safely sustain only 250,000 sheep without degradation—a far cry from the million or so that are currently eating away this resource base. Likewise, Syria's ranges currently feed triple the number of grazing animals they can safely support. In the initial stage of such degradation, inferior plant species replace more useful varieties. Then, sheep pastures become suitable only for the hardier goats and camels. Finally, in the words of Ibrahim Nahal, "in the advanced stage of deterioration the plant cover disappears as is apparent in many of the steppe zones in Syria, Jordan, Iraq and the United Arab Emirates, etc., where the rangelands have turned into semi-deserts covered with a layer of gravel or into semi-sand deserts."[9]

Rain-fed farmlands in much of the Middle East also show signs of ecological decline. Cultivation has been pushed onto lands with extremely low and unpredictable rainfall; as a result, soil erosion has accelerated and herders have been robbed of sorely needed grazing areas. In the Middle East, as in North Africa, the introduction of mechanical plowing has sometimes boosted the pace of soil degradation by increasing the land's susceptibility to erosion. One major result of improper cultivation in the Middle East has been, according to Nahal, "a distinct reduction in the per-hectare cereal yield in the rain-fed agricultural zone." National net production increases resulting from expansions in the irrigated area and in the total cropped area have helped to hide this decline in productivity.

Apart from intensively irrigated regions like the Nile and Indus Valleys, northwestern India is the world's most densely populated arid zone—a distinction that may turn out to be an epitaph. On average, more than 61 people now occupy each square kilometer of India's arid lands, which include the sandy wastes of the Thar Desert of western Rajasthan; a larger inhabited but desolate area surrounding it that is often loosely called the Rajasthan Desert; and other dry areas farther south and east. This density is but a small fraction of that supported in nearby irrigated valleys, but it is, as scientists at India's Central Arid Zone Research Institute recently observed, "quite high in view of limited resources."[10]

The practical consequence of this pressure has been the extension of cropping to sub-marginal lands, which has helped make northwest India perhaps the world's dustiest area. Meanwhile, as the amount of land available for grazing shrinks, the number of grazing animals swells—a sure-fire formula for overgrazing, wind erosion, and desertification. The area available exclusively for grazing in western Rajasthan dropped from 13 million to 11 million hectares between 1951 and 1961, while the population of goats, sheep, and cattle jumped from 9.4 million to 14.4 million. The livestock population has since continued to grow while the cropped area in western Rajasthan expanded further during the sixties from 26 percent to 38 percent of the total area. The net effect has been to squeeze the grazing area even more.[11]

Recent investigations by Indian scientists throw into question the widely held belief that the Thar Desert is rapidly marching toward New Delhi. Far from justifying complacency, however, these studies reveal the worsening plight of the millions who live in India's drier regions. In and around the desert portions of Rajasthan, yields of most major crops declined between 1954 and 1970. And in the Luni Block, a typical zone, "most pastures have been reduced to between 10 and 15 percent of their original productivity. The present forage deficiency of more than 50 percent is made good at the expense of the standing vegetation, and hence at the cost of future production." In 1958, about one-fourth of Luni Block was covered with a sheet of sand—some of it building into dunes. By 1976, 33 percent of the zone was so covered.[12]

Subjected to decades of accelerated deforestation, farming without adequate renewing of the soil, and overgrazing, much of west and central India now resembles a lunar landscape. Because of their low productivity, India's arid zones, which comprise a fifth of the country's total area, chronically drain the central government's meager emergency relief funds and food stocks.

No American countries are entirely arid and semi-arid. Still, desertification is taking place in many of the Western Hemisphere's drier regions. In the Argentinian states of La Rioja, San Luis, and La

Pampa, desert-like environments are being created. Large areas of Mexico and the southwestern United States have been degraded by overgrazing and woodcutting in the few hundred years since the Spanish invasion. The semi-arid tip of Brazil's Northeast is being desertified and, according to Brazilian ecologist J. Vasconcelos Sobrinho, desert-like zones are expanding in more humid interior portions of the Northeast as a result of the massive destruction of forests by ranching corporations and land-hungry farmers.[13]

In Chile's arid Coquimbo Region—which divides the lifeless Atacama Desert to the north and the productive irrigated valleys of central Chile—cactuses have replaced shrubs on some overgrazed lands, and on others native perennial plants have given way to less productive annuals and foreign species. As these pastures decline in quality, sheep replace cattle and then goats replace sheep. At the same time, the cultivation of hillsides has led to massive soil erosion and, on the steeper slopes, to a total loss of topsoil. As the authors of a report to the U.N. Conference on Desertification observe, the region's inequitable land-tenure pattern promotes ecologically unsound land use. The large and sparsely populated estates of the wealthy have room for proper grazing rotations, while the inadequate communal and personal holdings of the poor majority are overcrowded and increasingly degraded. Consequently, a high share of the region's adults are forced to migrate in search of income, and at least a quarter of the small children of Coquimbo are undernourished.[14]

Desertification is by no means confined to less developed countries. Ill-managed rangelands in Australia have lost productive plant species and topsoil. The dissolution of the American Great Plains into the Dust Bowl of the 1930s showed all too graphically the perils of plowing up lands best left in grass—just as the subsequent recovery and prosperity of much of that same area showed the benefits of better land husbandry.

Recent analyses of the conditions of many U.S. grazing lands leave little room for satisfaction, however. Reporting in 1975 on the 163 million acres of range it manages, the Bureau of Land Management (BLM) found half the area to be in only "fair" condition—meaning

that the more valuable forage species had been depleted and replaced by less palatable plants or by bare ground. Another 28 percent was in "poor" condition; stripped of much of its topsoil and vegetative cover, it produced only a fraction of its forage potential. Five percent of all BLM-controlled land was deemed in "bad" condition: with most of its topsoil gone, it could support only a sporadic array of low-value plants. The 50 million acres of land in "poor" or "bad" condition, an area equal to that of the state of Utah, was damaged primarily by overgrazing.[15]

One of the most dramatic and, in human terms, costliest examples of desertification in the United States is that of the huge Navajo Indian Reservation in northern Arizona and New Mexico. Encouraged by the U.S. government to become sheep farmers after their nineteenth-century subjugation, the Navajos proved to be adept shepherds. But, as the flocks multiplied in the absence of proper range-management techniques, the land—and ultimately the people living off it—paid an enormous price. Locations described by mid-nineteenth century travelers as lush meadows are today vistas composed of scattered sod remnants amid shifting sands and deep gulleys. Only a small fraction of the potential economic benefit is being harvested from these dusty, sagebrush-dotted lands that were once largely carpeted with grass.

In one zone that range specialists recently calculated could safely support 16,000 sheep at most, 11,500 Navajo people with 140,000 sheep were trying to wrest an existence. Before a new stock-reduction program took effect in the mid 1970s, their lot was growing increasingly difficult. In essence, individual families have been caught in an economic bind in which short-term self-interest dictates behavior that undermines the tribal patrimony. Yet, if herd reductions, careful grazing management, and reseeding can restore this zone to peak conditions, its carrying capacity will eventually rise above the current level by a factor of ten.[16]

While desertification clearly plagues rich as well as poor countries, the same processes of deterioration can have quite different effects on human life in different social contexts. Wealthier countries with diversified economies and public welfare programs can generally ab-

sorb localized declines in productivity without human catastrophe. In the United States, for example, many of those whose cattle are degrading public rangelands are well-off ranchers or investors, and even those Americans who can ill afford financial losses from desertification can sometimes migrate to better prospects or, if nothing else, collect welfare funds that at the least keep starvation at bay.

In contrast, tens of millions of Africans, Asians, and Latin Americans have nowhere to turn for aid as the basis of their livelihood erodes. Left in the wake of the global development process, they face chronic destitution and, when the rains fail, possible famine.

Droughts Are Inevitable

Water gives life to the desert, and a long-term shift in rainfall patterns can by itself transform the ecological character of a region. When deserts appear to be spreading, questioning whether climatic change might be the real culprit is only natural. Unfortunately, our understanding of climatic change and our knowledge of historical weather trends in most desert regions are too speculative to permit unequivocal conclusions about climate's contribution to desertification today.

Theories on the causes and nature of world climatic change are now almost as numerous as the scientists who study the problem seriously. That major climatic changes have occurred over exceptionally long time periods may not be hard to prove. For example, no climatologists doubt that the Indus River civilization flourished four thousand years ago in a moister climate than Pakistan enjoys today. But determining whether a present-day drought reflects a twenty-year dry cycle, a two-hundred-year cycle of rainfall patterns, the beginnings of a new climatic age, or simply a random event is far more difficult. At any rate, to review current theories and knowledge is to sense the urgent need for research efforts on climatic trends and their causes—natural and human. It is also to see without question that people and their livestock are helping to downgrade the carrying capacity of arid lands and to create new spots of desert.

Pointing to the unusual weather patterns and frequent droughts of the last decade, some analysts hold that a long-term change in the world's climate is an important cause of desertification. However, according to F. Kenneth Hare of the University of Toronto, who has reviewed available evidence on climate and desertification for the U.N. Conference on Desertification, there is "no firm basis for claiming that the extreme weather events of the 1970s are part of a major climatic variation." Extensive reviews of available rainfall records from North Africa reveal no evidence that rainfall has tapered off over the last one hundred years. Nor have Indian scientists studying the Thar Desert found any signs of recently increased aridity on its fringes. Similarly, available evidence indicates that rainfall levels in the Middle East have remained roughly the same for the last 5,000 years. South of the Sahara, as E. G. Davy concluded in a study of the Sahelian drought for the World Meteorological Organization, "no serious analysis of available data is known to show a falling trend of rainfall in the zone over the periods for which records are available." The length of the recent Sahelian drought proves nothing by itself, for droughts have lasted as long in the past. Indeed, the Sahelian rainfall in the period from 1907 to 1915 was probably just as light as it was during the recent drought, though low rainfall may have affected a smaller area then. Lengthy droughts will likely visit the region again whether a major climatic change is taking place or not.[17]

On the other hand, some climatologists believe that we are entering a new age of greater climatic instability; and, as Reid Bryson points out, we will not know for sure that we have entered a new climatic era until we are in the midst of it. Then too, climate is not immutable, and significant changes have occurred rapidly in the past. Anyway, what in historical light appears as a brief fluctuation in a long-term climatic trend can be catastrophic for farmers and other people dependent upon a particular weather pattern.

Some analysts believe that the landscape denudation associated with desertification may have a self-reinforcing climatic impact—prolonging or increasing the likelihood of droughts and, hence, of further devegetation. By some theories, the increased reflection of solar radiation from the surface that occurs when land is stripped of trees and

grasses may reduce the rainfall within a localized region; by others, a rising load of dust above a wind-eroded terrain suppresses potential rainfall. If such localized interactions between denudation and drought do exist, however, they can apparently be overridden by global climatic patterns—otherwise, droughts, once under way, might never end. A few climatologists go one step farther and hypothesize that worldwide desertification and deforestation have already altered surface reflectivity (or, depending on the theory, atmospheric dust levels) enough to affect the global climate.[18]

Probably the most significant effect of devegetation on the local water balance has to do not with climatic change but rather with the land's ability to capture and use what rain does fall. Rain striking barren, trampled, or sparsely vegetated ground is more apt to run off the surface than to soak in; not only are underground water and springs thereby left unregenerated, but the rate of soil erosion and the incidence of floods after heavy rains also rise. Depleted of their organic matter and structurally destroyed, soils can lose the ability to retain moisture from one rainy season to the next. Consequently, the natural vegetation may then bow to hardier species, while the loss of soil moisture and increased erosion sap the productivity of croplands. Thus, even when rainfall remains constant over time, land abuse can transform an area's plant life into that normally associated with a drier climate.

Whether or not a major climatic change is occurring, the experience of the world's drier zones makes it clear that droughts are unavoidable in arid environments. Although not precisely predictable, they should never come as a shock. Nor should droughts be perceived as unexpected natural disasters like tornadoes or earthquakes. Instead, they should be anticipated as harsh facts of life. Agriculture and culture in the desert must both be shaped to survive the driest years, not to push the land to its limits in years of adequate rainfall. Any other approach promises death and dislocation every time the rains fail for long.

Not only human suffering, but also the destruction of vegetative cover, the wind erosion of cultivated fields, and the formation of un-

usable wastelands all peak during droughts. Years or decades of steady rainfall encourage the growth of forage, the multiplication of herds, and the extension of cultivation to lands more safely left in grass; they also breed false confidence about the carrying capacity of the land. Then, when the rains finally fail, overabundant animals eat every available blade of grass on the weather-decimated rangeland until finally many starve to death, especially around wells. Tree-climbing goats eat the last bit of greenery, leaving behind wooden skeletons for the firewood gatherers. Crops fail to take root in the parched ground. The bare, plowed soil yields to the wind, and a dust bowl is created. If the rains remain absent long, sand dunes appear where none existed before. Nomads, farmers, and their surviving herds retreat before denuded lands, setting in process a self-reinforcing negative spiral as more and more refugees overcrowd and overgraze more and more land.

The years immediately following a severe drought can nurture bogus optimism about the land's capacity. By killing off a share of the herds and driving some of the former inhabitants from the region, nature has temporarily restored a shaky equilibrium. Smaller herds make more manageable demands on grazing lands, and returning rains bring grasses and shrubs back to life wherever the soil has not been seriously damaged. Refugees trickle back and, unless some new force intervenes to break the pattern, the same deadly cycle begins again.

Food Prospects in Desert Lands

Although minerals, tourism, and commerce sustain some inhabitants of desert lands, most such people—and nearly all those in less-developed arid countries—make their living from agriculture. The vast majority either grow their own food or sell or trade their crops for food and money. Unfortunately, many desert countries have fallen far behind the world as a whole and even behind many other poor countries in efforts to boost food output. Judged strictly on the basis of national per capita production data, which do not reflect the unequal distribution of food within countries, desert lands appear to be in deep trouble. (Add in the unequal distribution of income and the

picture grows grimmer.) Since desertification both reflects and contributes to the poor food-production record of the arid countries, a broader examination of food-production prospects in the desert lands is necessary.

Worldwide, grain production doubled and world population increased by nearly two-thirds between 1950 and 1975. Hence, global grain output per person rose by more than a third over the last quarter century. Few of the desert countries, however, shared in this progress. In fact, per capita grain output fell during this period in many. If data from sixteen predominantly arid or semi-arid developing countries that lack widespread irrigation are analyzed, a clear pattern of retrogression emerges. (See Table 1.)[19]

Table 1: Per Capita Grain Production in Sixteen Desert Countries, 1950-52 and 1973-75

Country	Per Capita Cereal Production (Kilograms)		Change (Percent)
	(1950-52)	(1973-75)	
Afghanistan	263	234	−11
Algeria	221	87	−61
Ethiopia	220	190	−14
Iran	182	185	+ 2
Iraq	269	156	−42
Jordan	143	79	−45
Lebanon	44	20	−54
Libya	99	106	+ 7
Mali	267	146	−45
Morocco	272	213	−22
Niger	303	169	−44
Senegal	142	186	+31
Sudan	102	150	+47
Syria	315	241	−24
Tunisia	216	184	−15
Upper Volta	193	180	− 7

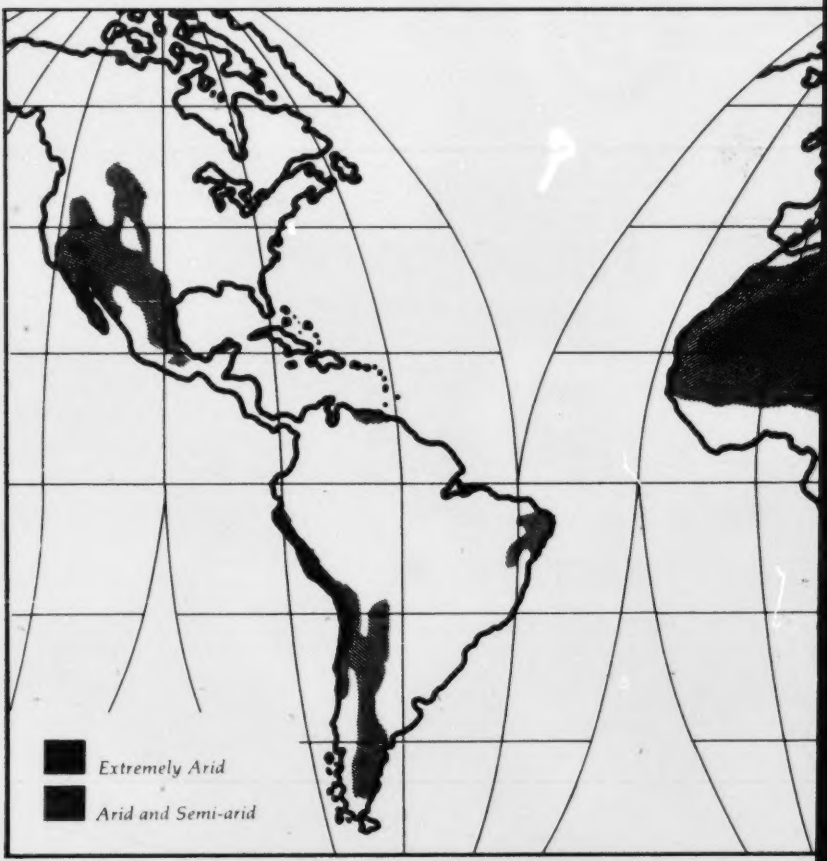
Source: U.S. Dept. of Agriculture.

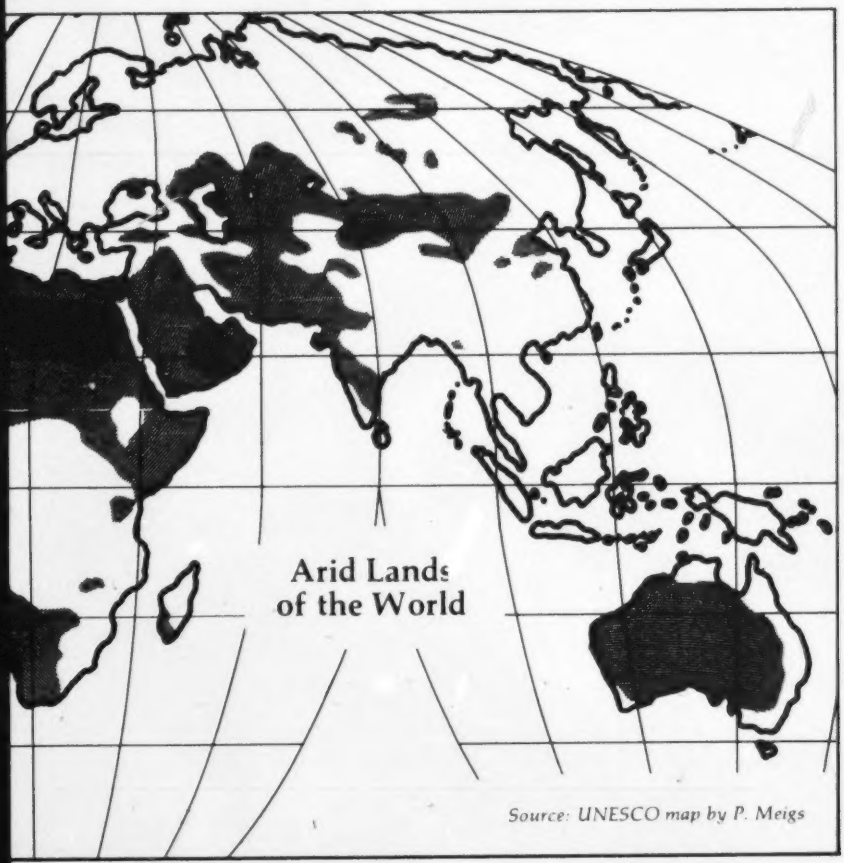
Only two of the sixteen countries—Senegal and Sudan—boosted per capita grain output significantly. By irrigating and cropping more land, these two countries overcame the effects of marked land degradation in some of their regions and nearly matched the average global improvement rate. In two other desert countries—Iran and Libya—grain production per person held its own over the last quarter century. But in the remaining twelve countries, per capita grain output declined. In some cases the decline has been modest; but in Algeria, Iraq, Jordan, Lebanon, Mali, and Niger, per capita production fell by at least 40 percent between the periods 1950-52 and 1973-75. In none of the countries showing declines was much grain-producing land shifted into non-food crops during these years—a shift that would explain the fall. In some, however, sizable areas are devoted to export crops such as cotton or peanuts.

When per capita food output within a country falls, consumption falls commensurately (with declines usually rationed not by need but by income), imports rise, or both. While data on the actual food-consumption trends among various income groups within the desert countries are not available, evidence of chronic and widespread undernutrition among the poor can be found in nearly all. Moreover, an increase in the dependence of many of these countries on outside food sources is readily documented.

Because of poor national food-production records (and, in a few countries, soaring net incomes accruing from oil wealth), net grain imports into these sixteen countries have more than tripled over the last fifteen years, rising from an annual average of 2.5 million tons in 1961-63 to an average of 7.6 million tons in the years 1975-77. (See Figure 1.) Algeria and Lebanon already import half or more of their total grain supply, as does Saudi Arabia (a desert country excluded from the list because data on its grain production is inadequate). Despite its intensive irrigation development, Egypt is also growing heavily dependent upon grain imports.

While different arid regions have different agricultural prospects and potentials, desertification reduces present and future food production wherever it occurs. It undercuts the benefits of agricultural in-


Extremely Arid
Arid and Semi-arid


Arid Lands
of the World
Source: UNESCO map by P. Meigs

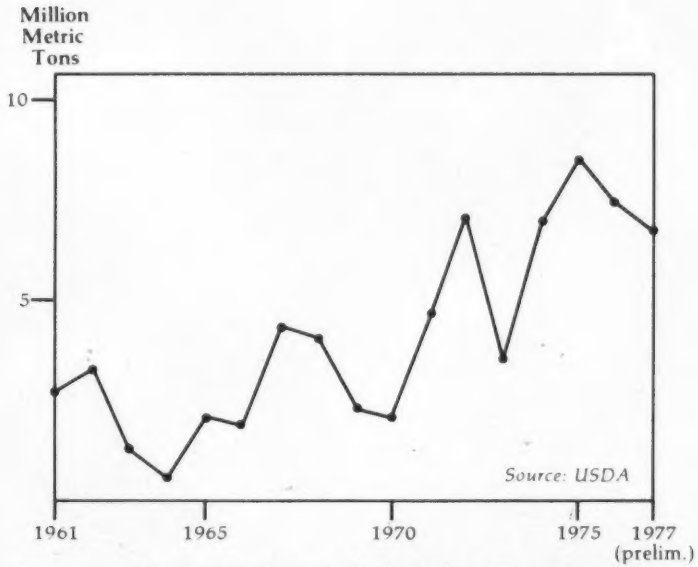


Figure 1: Net Grain Imports Into Sixteen Desert Countries, 1961-1977

vestments and can create poverty-producing wastelands even in countries that, judged by aggregate national statistics, appear to be making rapid agricultural gains. Concentrating investments in "choice" areas and development benefits in the hands of a privileged few can give a country a veneer of progress that blocks widespread environmental deterioration and social disintegration from view.

The state of underdevelopment itself usually indicates the presence of resources and productive potential now wasted. In a number of desert countries, for example, water resources are far from fully exploited. At the same time, the physical availability of underground

or river waters can not automatically be equated with irrigation potential; sometimes the costs of water development outweigh the resulting benefits. Furthermore, waterlogging, salinity, and the spread of water-borne diseases are common perils of irrigation in arid lands. Recent rice projects in West Africa, for example, have created new habitats for schistosomiasis parasites.[20]

Beyond unused irrigation potential, arable lands remain unplowed in a few desert areas. Fertile areas are being opened to farming, for example, as a result of the current international campaign against river blindness (onchocerciasis), fear of which has kept portions of West Africa's river valleys unoccupied. In other desert regions, however, such as Northwest India and many parts of Africa and the Middle East, farming has already been extended to areas where rainfall is fickle and soils are highly erosive. Good husbandry in these areas will, if anything, require reducing the cropped area.

In the wake of the Sahelian drought and other tragedies of the early seventies, development specialists rightly focus their attentions on the unexploited food-producing potential of the arid zones and on the possibility that some now-destitute areas could become breadbaskets. Even as the reforms and investments essential to such development are identified and implemented, however, some basic influences on the future food situation in desert lands must be held in mind.

Most of these lands will never be irrigated and, while substantial production gains could be realized in many desert countries, no technology within sight could sustain progress in dryland grain farming comparable to that enjoyed in moister zones in recent years. Research priorities within the arid zones have been skewed toward the development of profitable export crops, and until recently worldwide research efforts have reflected mainly the needs of farmers in temperate zones. But more fundamental constraints on dryland yields may exist; heavy fertilization is productive only when soil moisture is high. Even in the United States, the average yield of wheat—which is grown mainly on semi-arid lands—has increased by only two-thirds over the last generation while the per-hectare yield of corn—which is grown

mainly where rainfall is abundant—has tripled. No less skilled or progressive than the Iowa corn farmer, the Kansas wheat farmer must simply work with drier soil. Indeed, wheat yields have risen by scarcely a third in recent decades in Canada and Australia, two other agriculturally advanced countries that produce wheat under dry conditions. In contrast, where wheat is grown under high rainfall (as it is in Western Europe) or under irrigation (as in Pakistan and Mexico) impressive advances have been achieved.

Demography as well as production influences the food outlook in desert countries. Although undernutrition mainly results from the maldistribution of income rather than from an absolute shortage of food, its extent can easily multiply if population growth far outpaces agricultural growth. Sometimes, a whole nation's economic progress can be undermined as foreign exchange is soaked up by rising food imports.

Populations in many arid regions have, in the context of the technologies in use there, already reached the ecological danger point—as the breakdown of traditional fallow cycles and the spread of desert-like conditions make all too clear. In the arid, overgrazed areas directly on the fringes of deserts, populations must, virtually all analysts agree, be stabilized soon if further disaster and desertification are to be skirted. As Australian demographer John C. Caldwell writes of the Sahelian zone nomads, "their way of life is, without question, being imperiled by their growth in numbers."[21]

Some observers conclude that population growth in the more potentially productive semi-arid farming zones is not an important issue since considerable production gains could be achieved on these lands using known technologies. What those who so reason overlook is the tremendous demographic momentum created by the extremely high birth rates and the predominance of young people in many desert countries today. In eight of the sixteen desert countries analyzed, populations are now growing at 3 percent or more annually—a growth rate that, if sustained, would bring population increases of nineteenfold or more within a century.

"No less skilled or progressive than the Iowa corn farmer, the Kansas wheat farmer must simply work with drier soil."

Small families do not usually become the norm unless the social and economic climate is such that parents perceive an economic advantage in fertility control and unless most children live to become adults. Yet, in the desert countries as elsewhere, simply to wait hopefully for development to precipitate a fall in the birth rate is to court ecological disaster as well as to jeopardize the health of the millions of low-income women without access to family planning services. Even in a context of rapid and equitable economic development, the demographic transition to smaller families is likely—in the absence of special efforts to reach people with family planning services—to take decades or longer. Unfortunately, however, the desert countries have as a group been singularly slow to implement the goal agreed upon at the 1974 U.N. World Population Conference—providing all people with the knowledge and the means to plan their families.

Brightening the food prospects of the desert lands will require arresting and reversing desertification rapidly. It will entail implementing rural agricultural reform and distributing the fruits of development more equitably. It will also require slowing population growth. In the absence of such progress, economic and nutritional deterioration in many desert countries will continue. If it does, those individuals and countries able to afford it will buy their food on world markets; others will make do as best they can.

Social Causes and Social Solutions

An ecological phenomenon, desertification is a human problem. People cause it, people suffer its consequences, and only people can reverse it. Any schemes for enhancing the productivity of desert lands must, therefore, be grounded in an understanding of the cultures and economic predicaments of desert dwellers—and in the recognition that people undermine their own futures only when they see no alternative.

In the present institutional context, what is essential to the short-term survival of the individual who lives on arid lands often flies in the face of what the long-term survival of society dictates. For ex-

ample, nomadic families or clans need large numbers of animals just to meet their basic needs for milk and milk products—generally their principal foods. To these people, surplus livestock represent an investment. They also provide "drought insurance": when the rains fail, some animals can be sold off quickly, and, since some animals are bound to die during a drought, owning a large herd is protection against a total loss. Similarly, the individual farmer may have little choice but to plow up high-risk marginal fields. Yields on the better farmlands may be inadequate to feed the local populace and may even be falling as population pressures or the extension of cash cropping undermine traditional fallowing customs. Moreover, individual parents in desert lands naturally place a premium on large families because family deaths are frequent and extra children are needed to tend herds, gather wood, and carry water.

A better future for the people of the arid lands, then, depends upon forsaking a system in which the pursuance of personal aspirations encourages social suicide for a system in which those working to better their own lot are also furthering the long-term welfare of society. Livestock will have to be valued for its quality rather than its abundance, farmers will have to be supplied with the knowledge and equipment they need to grow enough food for all on the best-suited lands without running down these lands' long-term fertility, and the advantages of small families will have to be perceived by all couples.

A successful new order along these lines will almost certainly involve economic cooperation between those in the arid zones and those in cities or in regions with more moderate climates. An inward flow of resources, information, and goods to the desert edges is essential to a new order there; equally essential, in turn, is the outward shipment of meat and other agricultural products. But such cooperation must be based on a more just division between and within regions of the benefits of trade than has usually been made. What is more, exports from the desert lands—which can provide the resources needed for economic development—must co-exist with, rather than replace, a self-reliant, equitable, and environmentally sound food-production and distribution system.

Faced with the compelling need for a radical transformation of life on the desert margins, some analysts oversimplify and fail to address the fundamental predicament. Some governments, seeing the deterioration of grasslands, are determined to settle nomads at almost any cost. Watching the ubiquitous goat destroy trees, shrubs, and grasses, a few ecologists advocate killing off this hardy, well-adapted animal in arid lands. As water becomes scarce, local leaders demand that national governments or international aid agencies dig wells, but are unwilling to control the size of local herds and the access of livestock to the pastures surrounding a new well.

In the desert, as elsewhere, planners have much to learn from the plants, animals, and cultures that have withstood centuries of extraordinarily adverse environmental conditions. If the ecological balance historically maintained by most nomadic groups was rather wretched, predicated as it was on high human death rates, these people used the life-defying desert remarkably resourcefully. In popular mythology, nomads are often pictured as aimless wanderers. But in fact, nomadic movements nearly always harmonize with the seasonal rhythm of climate and plant life. They are geared to permit animals to find adequate forage throughout the year and to permit the regrowth of grazing lands.[22]

A return to an earlier historical age is no more desirable than likely. The harsh natural selection that underlay nomadic systems in the past is no longer ethically acceptable to most people today. In any case, rudimentary modern medicine has trickled into the arid zones well ahead of advanced agricultural technology, helping to push down death rates. Moreover, national boundaries now divide natural ecological zones artificially and restrict the traditional movements of nomadic groups, while the spread of sedentary agriculture further limits migrations. In an effort to keep the nomads from being squeezed into the desert, the government of Niger in 1961 set a northern boundary of legal cultivation. But the northward advance of farming, set back only temporarily by the years of severe drought, has continued all the same. Today, farming takes place on sites at least 100 kilometers past the legal limit and is practiced illegally in

the protected zone by both nomadic groups and others moving up from the south.[23]

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Although many traditional nomadic practices are no longer viable, adopting some modernized version of the nomadic way of life may be the only way that those in the arid desert fringes can safely exploit these areas' protein-producing potential. Regional management schemes, in which clan leaders regulate grazing and migratory movements according to natural conditions and the advice of range specialists, represent one possibility. Such systems would ideally retain much of the flexibility of nomadic ways while also permitting the application of modern methods to improve livestock quality. Once grazing was under control, wells and pasture improvements could be introduced with less chance that their long-run effects would be twisted.

More specifically, one possible approach would be to establish large herding cooperatives of the sort Jeremy Swift, a British specialist in pastoral development, has proposed for Somalia. Cooperatives could combine ecologically sound management with both economic progress and social security for the nomads. Writes Swift:

> Pastoral cooperatives would be an appropriate form of organization to take on some of the functions of traditional pastoral society, such as the regulation of grazing, security against loss of animals, regulation of conflicts over land use, and making investments in the land. Pastoral cooperatives would also be an appropriate vehicle for taking the state to the nomads and for making their views and wishes known to the state, a channel of two-way communication that is needed particularly during a phase of rapid transformation of the sort now starting in Somalia.[24]

A key to the success of any livestock scheme is the reduction of herd sizes. According to some specialists, the number of grazing animals maintained in the Sahel up to 1972 and 1973, as the lengthy drought reached its climax, was at least double what the zone's ranges can sustain without damage. The drought cut animal numbers steeply,

but not enough to put grazing and grasses back into balance. Yet numbers deceive: if animal numbers were maintained at *half* the 1971 level and modern management techniques were implemented, the region's output of meat and milk could easily be *double* the 1971 level.[25]

This somewhat paradoxical formula reflects the nature of livestock growth. Roughly half the food consumed by a grazing animal is required just for physiological maintenance; another fourth is required largely for reproduction, and the final fourth goes into milk production, growth, and fat storage. Any cutback in feeding forced by the depletion of pastures is mostly at the expense of these final functions. Of course, the benefits of a more efficient grazing system that emphasizes productivity over herd numbers can be realized only if valuable livestock products are at the same time put within consumers' reach. And herd reductions will be permanent only if the people involved understand the need for change, participate in the decision-making process as change is carried out, and see a genuine opportunity for a better life in the new order.

Improving farming in the sedentary zones is as crucial to arresting desertification as controlling grazing is. Agricultural progress is essential not only to provide food, employment, and income to the mounting populations of these areas, but also to halt the destructive spread of cultivation onto pasturelands. In past decades, most research and investment in arid-zone agriculture pertained to the production of cash crops like cotton and peanuts for export, or revolved around large-scale irrigation schemes intended to bring desert regions under intensive production of food or fiber. Simple subsistence farmers, growing millet or sorghum for family consumption and trade with nomads or urbanites, have frequently been neglected—with sorry consequences for the land. As political scientist Michael F. Lofchie describes the situation in Africa, "Decades of over-concentration on export cultivation have left the continent's food-producing regions badly undersupplied with infrastructure, deprived of government services, desperately short of capital for development, and technologically pre-feudal. As a result, any attempt to improve Africa's food-producing capability will need to concern itself with a fundamental

structural transformation of the rural economy." But, as Lofchie goes on to note, shifting governmental priorities toward food crops and extending the benefits of the development process to more people involve more than technical decisions: "Policies which have the potential to undermine the established economic primacy of the export sector would run directly counter to the large and powerful array of social groups which have a stake in the profitability of the export economy."[26]

Export crops, a principal source of foreign exchange for many arid countries, can be one key to economic progress. But if their expanded cultivation is not accompanied by careful land-use planning, and if a major share of the income they produce is not earmarked for the betterment of rural economic and social prospects, the lot of the rural poor may deteriorate and environmental stresses intensify. All too often, the foreign exchange and taxes collected from export crops wind up mainly supporting bloated government bureaucracies and the luxurious lifestyles of the urban elite.[27]

In many dryland farming areas, population growth prohibits a return to the ecologically sustainable fallow or rotation systems once used with success. The only alternative is to adopt new cropping systems that minimize erosion and that employ crop rotations, water-conserving techniques, animal manures, green manures, and, where moisture permits, perhaps chemical fertilizers. Such sustainable dryland-farming techniques have been developed and proven effective in Israel, Australia, the Soviet Union, the United States, and other countries. Indeed, their use could be enhanced if agricultural technologies and experiences were exchanged among developing countries—a generally neglected form of technology transfer. Near the city of Kano in semi-arid northern Nigeria, for example, ecologically sound methods of continuous cropping that involve the heavy application of human and animal wastes to the fields have evolved, and these practices could well prove workable in other areas.[28]

As agricultural modernization is pursued, governments and aid agencies need to watch carefully the evolution of land-tenure patterns and to insure that the social goals of development are not undercut

"Populations cannot be protected against famine over the long run unless everyone shares in the benefits of agricultural modernization."

by the concentration of landholdings and production benefits in the hands of a few. Land in many arid regions is still allocated by traditional tribal criteria; but as land becomes more scarce or when its value suddenly jumps after it is irrigated, traditional tenure patterns begin to break down. If "development" entails the emergence of huge mechanized, irrigated farms owned by wealthy individuals or corporations—as it now does in arid northern Mexico—then the welfare of large numbers of people may actually be worsened under the guise of "progress."

In addition to improved agricultural methods, tree-planting programs are urgently needed nearly everywhere that dryland agriculture is practiced. In the U.S. Great Plains, the thousands of windbreaks that were planted during and after the 1930s helped stabilize a system that once threatened to become a permanent dust bowl. Besides reducing wind erosion around fields and, in some circumstances, stabilizing sand dunes, tree-planting programs can also help relieve the critical shortage of firewood that now plagues every arid region in the developing world.[29]

A major goal of arid lands development must be to prepare people and economies to live through the inevitable droughts without traumas. Famines in the deserts are not simply climatically-induced disasters; they are social phenomena, resulting when climatic extremes affect vulnerable populations. Accordingly, as populations in drought-prone areas grow in the absence of widely shared rural development, the number of people susceptible to famine grows as well.[30]

Improving local grain-reserve facilities in desert regions can help tide people over during years of poor rainfall, just as better crop-surveillance and reporting mechanisms can expedite the flow of outside aid to regions where crops fail. But populations cannot be protected against famine over the long run unless everyone shares in the benefits of agricultural modernization and unless the development process creates employment opportunities for all. When only some members of society enjoy rising prosperity and economic security, others who lack access to land, improved technologies, or jobs may starve at the

whim of "nature." Hence, protection against famine is not a simple technological problem; its success depends upon the broad shape of national development and the character of prevailing socioeconomic institutions.

A problem as awesome as desertification has not gone unnoticed by scientists, by directly affected people, and by some governments. For decades scientists have warned that disasters were brewing in the deserts; but their warnings failed to spur the political changes essential to solutions. Individuals who have witnessed environmental deterioration and have felt its impoverishing impact on their lives have had no choice but to act in the interest of their own survival. Probably every national government in the desert areas has sponsored programs to combat one or another aspect of desertification. Most such efforts, however, have been too scattered or too weak to reverse widespread degradation.

Some striking success stories do exist. Much of Israel's Negev Desert, which has suffered thousands of years of overgrazing and deforestation, is now productive and prosperous as a result of innovative irrigation practices, improved dryland farming, and controlled grazing. China, which, like Israel, has been uncommonly successful at mobilizing people to accomplish common goals, has halted deterioration and boosted productivity in many of its huge desert areas.[31] Algeria, Iran, Somalia, and Sudan are among the countries that have recently initiated large-scale programs to restore their environments. Plans are now being laid for an internationally funded region-wide agricultural development program in the Sahelian countries of West Africa.

That massive efforts to protect and enhance the productivity of the world's arid lands make good economic sense has been well established. By U.N. estimates, cumulative degradation of rangelands and non-irrigated farmlands has held their combined annual productivity more than $12 billion below its potential level; if damages due to waterlogging and salinity are added, the yearly losses total nearly $16 billion. Fortunately, as Harold Dregne, a leading analyst of arid land agriculture, has emphasized, few of the degraded areas have passed the point of no return. In most, wise management can

restore most if not all of the land's productivity. Furthermore, according to U.N. calculations, anti-desertification investments in the $400 million-per-year range worldwide would yield a handsome financial return.[32]

Both the costs of desertification and the benefits of combatting it entail much more, of course, than losses or gains in agricultural output. For some people, a decline in the quality of the land means a decline in the quality of the diet and, hence, means chronic ill health. By reducing a region's opportunities for productive employment, desertification can create "ecological refugees" who must leave their homelands in search of a livelihood—and who swell the ranks of migrants gathering in the cities of the developing world. The loss of agricultural opportunities equals the loss of opportunities for economic growth; and, when lands are so degraded that they cannot be recovered, a nation's natural assets have been permanently reduced.

The negative environmental trends called desertification are widespread, long-standing, and, in many areas, accelerating. The technologies needed for reversing them are for the most part already available. Many essential programs and policies, ranging from land-quality monitoring to land-use planning, from the development of new cultivation methods to the planting of trees, are summarized in the "Plan of Action to Combat Desertification" to be adopted by the 1977 U.N. conference. The conference organizers have, in fact, emphasized the technical and financial feasibility of arresting desertification everywhere within a generation.

Too commonly lacking, however, is a political commitment to the reversal of desertification commensurate with the size of the challenge. Faced with immediate crises—famines, strikes, and political intrigues—governments find it difficult to devote substantial resources to combatting a seemingly long-term and nearly invisible problem like ecological deterioration. They are especially reluctant to do so when a shift in national priorities and investment patterns goes against the short-term personal interests of powerful elites. Governments that procrastinate too long, however, may one day be forced by events to see that their deteriorating agricultural landscapes are mirrored in

deteriorating social and economic conditions. The varied consequences of desertification—undernutrition and famine, unemployment and migration, deepening poverty and human desperation—are neither distant nor invisible.

Notes

1. U. N. Conference on Desertification, *Desertification: An Overview*, Nairobi, August 29–September 9, 1977. The U. N. Conference is including the problems of waterlogging and salinity in irrigated fields within the concept of desertification. While massive, these problems will not be discussed in this paper since their causes and solutions differ considerably from those of the problems of rangelands and non-irrigated farmlands described here. See Chapter 7 in Erik Eckholm, *Losing Ground: Environmental Stress and World Food Prospects* (New York: W. W. Norton, 1976) for a discussion of the scope and causes of waterlogging and salinity problems.

2. Andrew Warren and Judith K. Maizels, *Ecological Change and Desertification*, A Component Review for the U. N. Conference on Desertification (London: University College, October 1976).

3. M. Kassas, "Arid and Semi-Arid Lands: An Overview," in United Nations Environment Programme, *Overviews in the Priority Subject Area: Land, Water and Desertification* (Nairobi: February 1975).

4. U. S. Agency for International Development, Office of Science and Technology, *Desert Encroachment on Arable Lands: Significance, Causes and Control* (Washington, D.C.: August 1972).

5. Samir I. Ghabbour, "Some Aspects of Conservation in the Sudan," *Biological Conservation*, April 1972.

6. H. F. Lamprey, "Report on the Desert Encroachment Reconnaisance in Northern Sudan, 21 October to 10 November 1975," Nairobi, undated; M. Kassas, "Desertification versus Potential for Recovery in Circum-Saharan Territories," in Harold E. Dregne, ed., *Arid Lands in Transition* (Washington, D.C.: American Association for the Advancement of Science, 1970).

7. Jon Tinker, "Sudan Challenges the Sand-Dragon," *New Scientist*, February 24, 1977.

8. H. N. Le Houérou, "North Africa: Past, Present, Future," in Dregne, *Arid Lands in Transition*.

9. Ibrahim Nahal, "Some Aspects of Desertification and their Socio-Economic Effects in the ECWA Region," presented to the U. N. Conference on Desertification by the Economic Commission for Western Asia, 1977.

10. Central Arid Zone Research Institute, "Sociology—Main Results," Jodhpur, India, undated.

11. M. S. Swaminathan, "Our Agricultural Future," India International Centre, New Delhi, 1973.

12. H. S. Mann, S. P. Malhotra and J. C. Kalla, "Desert Spread: A Quantitative Analysis in the Arid Zone of Rajasthan," *Annals of Arid Zone*, Vol. 13, No. 2, 1974; Central Arid Zone Research Institute, "Luni Development Block: A Case Study on Desertification," prepared for the U. N. Conference on Desertification, Jodhpur, September 1976. Quote from summary of Luni Case Study in U. N. Conference on Desertification, "Synthesis of Case Studies of Desertification," Nairobi, August 29–September 9, 1977.

13. Cesar F. Vergelin, "Water Erosion in the Carcarana Watershed: An Economic Study," dissertation, University of Wisconsin, Madison, 1971; U. S. Agency for International Development, *Desert Encroachment on Arable Lands*; J. Vasconcelos Sobrinho, "O Deserto Brasileiro," Universidad Federal Rural de Pernambuco, Recife, 1974; J. Vasconcelos Sobrinho, "Problemática Ecológia do Rio São Francisco," Universidad Federal Rural de Pernambuco, Recife, 1971.

14. Coquimbo Region Case Study summarized in U. N. Conference on Desertification, "Synthesis of Case Studies of Desertification."

15. Council on Environmental Quality, *Environmental Quality*, Sixth Annual Report (Washington, D.C.: December 1975).

16. Data supplied by Bureau of Indian Affairs. The zone discussed was until recently open for joint use by Navajos and Hopis, but in fact was used almost entirely by Navajos. The area has now been divided between the tribes, and Navajos living in the Hopi sections are to be relocated. Land degradation on the Navajo Reservation is chronicled with photographs in *Along the Beale Trail: A Photographic Account of Wasted Rangeland* (Washington, D.C.: Office of Indian Affairs, 1939).

17. F. Kenneth Hare, *Climate and Desertification*, A Component Review for the United Nations Conference on Desertification (Toronto: University of Toronto Institute for Environmental Studies, 1976); F. Kenneth Hare, "The Story So Far," *Mazingira*, No. 1, 1977; Le Houérou, "North Africa"; B. B. Roy and S. Pandey, "Expansion or Contraction of the Great Indian Desert," *Proceedings of the Indian National Science Academy*, Vol. 36, No. 6, 1970; Nahal, "Some Aspects of Desertification"; Anders Rapp, *A Review of Desertization in Africa—Water, Vegetation, and Man* (Stockholm: Secretariat for International Ecology, 1974).

18. In *Climate and Desertification,* Hare reviews various theories about desertification-drought feedback effects. Reid Bryson's theory that global climatic changes are related to rising atmospheric dust levels was presented in "The Sahelian Effect," University of Wisconsin Institute for Environmental Studies, Madison, August 1973.

19. Among sizable, predominantly desert countries of the developing world, Chad, Mauritania, and Saudi Arabia had to be omitted from our list because production data were not available. Egypt and Pakistan were not included because their agriculture is almost exclusively irrigated. Australia and Israel are, of course, more developed and have modern agricultural sectors. We are grateful to Robert Wuhrman for his assistance in compiling data on grain production and trade in desert countries.

20. See Chapter 9 in Erik Eckholm's forthcoming book, *The Picture of Health: Environmental Sources of Disease* (New York: W. W. Norton, 1977) for a discussion of irrigation's role in the global spread of schistosomiasis.

21. John C. Caldwell, *The Sahelian Drought and its Demographic Implications* (Washington, D.C.: American Council on Education, Overseas Liaison Committee, December 1975).

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